The Interactive Effect of GHR-Exon 3 and -202 A/C IGFBP3 Polymorphisms on rhGH Responsiveness and Treatment Outcomes in Patients with Turner Syndrome

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The Interactive Effect of GHR-Exon 3 and −202 A/C IGFBP3 Polymorphisms on rhGH Responsiveness and Treatment Outcomes in Patients with Turner Syndrome


Objective: The objective of the study was to assess the individual and combined influence of GHR-exon 3 and −202 A/C IGFBP3 polymorphisms on the short- and long-term outcomes of rhGH therapy in patients with TS.

Design and Patients: GHR-exon 3 and −202 A/C IGFBP3 genotyping (rs2854744) was correlated with height data of 112 patients with TS who remained prepubertal during the first year of rhGH therapy and 65 patients who reached adult height after 5 ± 2.5 yr of rhGH treatment.

Main Outcome Measures: First-year growth velocity and adult height were measured.

Results: Patients carrying at least one GHR-d3 or −202 A-IGFBP3 allele presented higher mean first-year growth velocity and achieved taller adult heights than those homozygous for GHR-fl or −202 C-IGFBP3 alleles, respectively. The combined analysis of GHR-exon 3 and −202 A/C IGFBP3 genotypes showed a clear nonadditive epistatic influence on adult height of patients with TS treated with rhGH (GHR-exon 3 alone, R² = 0.27; −202 A/C IGFBP3, R² = 0.24; the combined genotypes, R² = 0.37 at multiple linear regression). Together with clinical factors, these genotypes accounted for 61% of the variability in adult height of patients with TS after rhGH treatment.

Conclusion: Homozygosity for the GHR-exon3 full-length allele and/or the −202 C-IGFBP3 allele are associated with less favorable short- and long-term growth outcomes after rhGH treatment in patients with TS. (*J Clin Endocrinol Metab* 97: E671–E677, 2012)
Recombinant human (rh) GH is an approved therapy to improve final height of patients with Turner syndrome (TS), a common cause of short stature (1). Typically, patients with TS exhibit considerable interindividual variability regarding short- and long-term growth responses to rhGH therapy (2–5). Prediction models of responses to rhGH based on clinical parameters had limited capacity to explain this variability in TS as well as in other rhGH-treated growth disorders (6), suggesting that further parameters, such as genetic factors, may be missing from current models (4).

A meta-analysis has demonstrated that GH-deficient (GHD) and non-GHD children homozygous or heterozygous for the growth hormone receptor (GHR) exon 3 deleted (GHRd3) isoform had slightly better short-term growth outcomes after rhGH therapy than children homozygous for the full-length (fl) GHR isoform (GHR/fl) (7). Three studies analyzed this polymorphism in patients with TS concerning the first-year growth response to rhGH treatment, without reproducible results (8–10), whereas only one study analyzed the influence of the GHR-exon 3 deleted isoform on final height (8). Additionally, a single-nucleotide polymorphism (SNP) located at position −202 of the IGF binding protein (IGFBP)-3 promoter region (rs2854744) has also been involved in rhGH pharmacogenetics of growth hormone deficiency (11) and children born small for gestational age (12).

In comparison with other non-GHD indications of rhGH therapy, TS is a more homogeneous cause of growth impairment and, consequently, constitutes a better model to test the influence of genetic variants on the rhGH growth response. Thus, the aim of this study was to assess the individual and combined influence of GHR-exon 3 and −202 A/C IGFBP3 polymorphisms on the short- and long-term outcomes of rhGH therapy in a large group of patients with TS.

**Patients and Methods**

**Subjects**

The study protocol was approved by the Hospital Ethics Committee, and informed consent was obtained from all patients or their parents before starting the molecular studies. One hundred twelve patients with TS were selected using the following criteria: 1) the presence of a karyotype containing a missing or a structurally aberrant X chromosome; 2) rhGH treatment on a daily schedule, and 3) patients remaining prepubertal throughout the first year of therapy. First-year growth velocity was determined after an observation period of 9–15 months. In addition, adult height was analyzed after 5 ± 2.5 yr of rhGH treatment in 65 patients. Adult height was defined by a documented growth velocity less than 1 cm/yr during the last 12 months. Patients were evaluated at baseline and every 4 months during rhGH treatment. Evaluations were performed at the same period of the day and included measurements of weight (measured with a digital scale), standing height (mean of three measurements on a stadiometer) expressed in centimeters, and SD scores (SDS) for sex and age (13). Body mass index (BMI) was calculated (weight/height²) and expressed as SDS (14). Target height was calculated [(father’s height + mother’s height – 13 cm)/2] and expressed as SDS. Left hand and wrist x-rays for bone age (BA) determination was assessed by the method of Greulich and Pyle (15).

**Hormone assays**

IGF-I levels were obtained at the start of treatment and near the end of the first year of rhGH therapy in 80% of the patients. IGF-I was measured by RIA after ethanol extraction (Diagnostic Systems Laboratories, Webster, TX) (73% of patients) or by chemiluminescence assays (IMMULITE; Diagnostic Products Corp., Los Angeles, CA) (27% of patients). IGFBP-3 levels were obtained at the start of treatment and near the end of the first year of rhGH therapy in 60% of the patients. IGFBP-3 was measured by immunoradiometric assay (Diagnostic Systems Laboratories) (66% of the patients) or by chemiluminescence assays (IMMULITE) (34% of the patients). IGF-I and IGFBP-3 levels were expressed as SDS for age and sex according to reference values provided by the respective assay kits.

**Molecular studies**

Genomic DNA was isolated from peripheral blood leukocytes by standard methods from all patients. The frequency of GHR transcript variants regarding the presence (GHRfl) or absence (GHRd3) of exon 3 was tested in all patients using a previously described multiplex PCR assay (16, 17). The polymorphism −202 A/C IGFBP3 (rs2854744) was genotyped by allelic discrimination in a Real Time 7500 system (Applied Biosystems, Foster City, CA) equipment using specific probes and primers (186389191-1, TaqMan SNP genotyping assay; Applied Biosystems) according to the manufacturer’s instructions. Ten percent of all samples were randomly re-genotyped for quality control. The agreement of the genotypes determined by the blinded quality control samples was 100%.

**Statistical analysis**

Qualitative variables are listed as frequencies and percentages, whereas quantitative variables are shown as mean ± SD. Patients were compared by genotype relative to clinical and hormonal characteristics. The short-term response to rhGH was evaluated by growth velocity in the first year of treatment. The long-term response to rhGH was assessed by adult height SDS and adult height SDS adjusted for target height SDS. One-way ANOVA followed by a Tukey test was used for comparisons according to the additive model, whereas the t test was used for comparisons according to the dominant model. Numerical variables that did not demonstrate parametric distribution were analyzed by Kruskal-Wallis one-way ANOVA on ranks or Mann-Whitney rank sum test. Nominal variables were compared by a χ² or Fisher exact test, as appropriate. To assess whether genetic variants had independent prognostic significance for outcome, we performed single- followed by multiple-regression analyses adjusting for the established influential factors. The evaluated clinical factors included karyotype, birth length and weight, chronological age, BA, height, BMI at the start of treatment, target height, maternal and paternal height, induced or sponta-
neous puberty, age and height at the start of puberty, rhGH doses, and duration of treatment. A \( P < 0.05 \) was considered statistically significant. All statistical analyses were performed by SigmaStat for Windows (version 3.5; SPSS, Inc., San Rafael, CA).

**Results**

**Patients’ characteristics and genotyping distribution**

At the start of rhGH therapy with a mean dose of 48 \( \mu g/kg \cdot d \), the patients with TS (\( n = 112 \)) had a chronological age of 11.2 \( \pm 3.8 \) yr, bone age delay (mean BA of 9.0 \( \pm 3.1 \) yr), and a mean height SDS of \(-3.2 \pm 1.1\). The onset of puberty, induced in 92 and spontaneous in 20 patients, was at 14.3 \( \pm 2.4 \) yr, and 65 patients achieved adult height (mean height SDS of \(-2.0 \pm 1.0\)) after 5.0 \( \pm 2.5 \) yr of rhGH treatment.

All patients were genotyped for GHR-exon 3 [genotype distribution: 53.6% (fl/fl); 37.5% (fl/d3); and 8.9% (d3/d3)] and \(-202\) A/IGFBP3 polymorphism [genotype distribution: 17% (A/A); 48.2% (A/C); and 34.8% (C/C)]. The genotype distributions were in Hardy-Weinberg equilibrium. Genotypic groups were similar concerning karyotype distribution, chronological and bone ages at the start of treatment, basal BMI, parental height, the frequency of spontaneous or induced puberty, age at puberty onset, mean rhGH dose, and duration of therapy (Tables 1 and 2). However, patients homozygous for GHR-fl allele and for \(-202\) C-IGFBP3 allele had lower basal height SDS than patients carrying GHR-d3 and \(-202\) A-IGFBP3 alleles, respectively, at the start of therapy (Tables 1 and 2). Patients homozygous for the \(-202\) C-IGFBP3 allele also had IGFBP-3 levels on average \(-1.0 \) SDS lower [95% confidence interval (CI) \(-1.5 \) to \(-0.5\); \( P < 0.001 \)] than carriers of at least one \(-202\) A-IGFBP3 allele.

**Clinical correlations**

**Short-term growth response**

Patients homozygous for the GHR-fl allele demonstrated lower growth velocity in the first year of rhGH treatment when compared with those patients with at least one GHR-exon 3 deleted allele (Table 1). As a group, patients with the GHR d3/* genotype had growth velocity on average 1.4 cm/yr higher than those with GHR fl/fl genotype [95% CI 0.7–2.0 cm/yr; \( P < 0.001 \)]

Similarly, patients homozygous for the \(-202\) C-IGFBP3 allele presented lower growth velocity in the first year of
rhGH therapy when compared with those carrying at least one 
−202 A/C IGFBP3 allele (Table 2). The −202 A/* 
IGFBP3 genotype group had a growth velocity on average 
0.8 cm/yr higher than the −202 C/C-IGFBP3 group (95% 
CI 0.05–1.6 cm/yr, P = 0.037). There was a significant 
relationship between −202 A/*-IGFBP3 group and circu-
ulating IGFBP-3 levels at baseline (IGFBP-3 SDS 0.2 ± 
1.3 for the −202 A/*-IGFBP3 group and −0.8 ± 1.0 for 
the −202-C/C-IGFBP3 group; P < 0.001) and after the 
first year of rhGH treatment (IGFBP-3 SDS 0.9 ± 1.3 
for the −202 A/*-IGFBP3 group and 0.4 ± 1.0 for the 
−202-C/C-IGFBP3 group; P = 0.039).

Combined analysis showed that GHR-exon 3 and −202 
A/C IGFBP3 genotypes had an interactive influence on the 
first year growth velocity (Table 3). Patients with TS pre-
senting the combination of the two favorable genotypes 
(GHR-exon 3 d3/* + −202 A/* IGFBP3) had first-year 
growth velocity on average 1.8 cm/yr (95% CI 1.0–2.6 cm/ 
yr, P < 0.001) higher than individuals with unfavorable com-
bined genotypes (GHR-exon 3 fl/fl + −202 C/C IGFBP3), 
whereas patients with intermediate genotypes (fl/fl + A/* 
or d3* + C/C) had in-between values (Table 3).

Multiple linear regressions adjusting for other clinical 
variables showed that GHR-exon 3 genotype was an in-
dependent prediction variable for first-year growth velo-
city. Together with chronological age (P < 0.001) and basal 
BMI SDS (P = 0.018) at onset of rhGH therapy, GHR-
exon 3 genotype (P = 0.001) explained 40% of first-year 
growth velocity variability. There was no significant in-
crement on first year growth velocity prediction after add-
ing −202 A/C IGFBP3 polymorphism (R² = 0.41 with 
and R² = 0.40 without the inclusion of −202 A/C IGFBP3 
genotypes).

Long-term growth response

The positive influence of the GHR-d3 and −202 A-
IGFBP3 alleles noted on first-year growth velocity was 
also observed on adult height of patients with TS after 
rhGH therapy, with or without adjustment for target 
height (Tables 1 and 2). Patients carrying at least one 
GHR-d3 allele were 1.1 SDS (95% CI 0.7–1.5, P < 0.001) 
taller than those homozygous for the GHR-fl allele (Table 
1). Carriers of at least one −202 A-IGFBP3 allele were 1.0 
SDS (95% CI 0.5–1.5, P < 0.001) taller than those homo-
zygous for the −202 C-IGFBP3 allele (Table 2).

Combined analysis including GHR-exon 3 and −202 
A/C IGFBP3 genotypes demonstrated that they had an independent and interactive influence on adult height. De-

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**TABLE 2.** Clinical and hormonal features of 112 patients with TS grouped according to −202 A/C IGFBP3 genotype

<table>
<thead>
<tr>
<th>−202 A/C IGFBP3 genotype</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/A</td>
<td>A/C</td>
</tr>
<tr>
<td>Number of patients for short-term outcomes</td>
<td>19</td>
</tr>
<tr>
<td>Karyotype 45,X</td>
<td>57%</td>
</tr>
<tr>
<td>Target height SDS</td>
<td>−0.5 ± 0.6</td>
</tr>
<tr>
<td>Chronological age at the start of therapy (yr)</td>
<td>11 ± 3.5</td>
</tr>
<tr>
<td>BA at the start of therapy (yr)</td>
<td>10 ± 2.3</td>
</tr>
<tr>
<td>Height SDS at the start of therapy</td>
<td>−3.0 ± 0.9</td>
</tr>
<tr>
<td>BMI SDS at the start of therapy</td>
<td>0.4 ± 0.8</td>
</tr>
<tr>
<td>Mean rhGH dose (μg/kg · d)</td>
<td>48</td>
</tr>
<tr>
<td>First-year growth velocity (cm/yr)</td>
<td>7.4 ± 1.6</td>
</tr>
<tr>
<td>IGF-I SDS before rhGH therapy</td>
<td>−0.3 ± 1.1</td>
</tr>
<tr>
<td>IGF-I SDS after first year of rhGH therapy</td>
<td>1.3 ± 1.0</td>
</tr>
<tr>
<td>IGFBP-3 SDS before rhGH therapy</td>
<td>0.2 ± 1.1</td>
</tr>
<tr>
<td>IGFBP-3 SDS after first year of rhGH therapy</td>
<td>1.2 ± 0.5</td>
</tr>
<tr>
<td>Number of patients with long-term outcomes</td>
<td>10</td>
</tr>
<tr>
<td>Spontaneous/induced puberty</td>
<td>2.8</td>
</tr>
<tr>
<td>Chronological age at onset of puberty (yr)</td>
<td>15.0 ± 1.6</td>
</tr>
<tr>
<td>rhGH therapy before onset of puberty (yr)</td>
<td>3.1 ± 2.0</td>
</tr>
<tr>
<td>Duration of rhGH therapy (yr)</td>
<td>5.0 ± 2.3</td>
</tr>
<tr>
<td>Adult height SDS</td>
<td>−1.0 ± 0.7</td>
</tr>
<tr>
<td>Adult height-target height SDS</td>
<td>−0.5 ± 0.7</td>
</tr>
<tr>
<td>Height gain SDS</td>
<td>1.7 ± 0.8</td>
</tr>
</tbody>
</table>

<sup>A/*</sup> indicates combined A/C and A/A −202-IGFBP3 genotypes. ns, Not significant.

<sup>a</sup> One-way ANOVA.
<sup>b</sup> Student t test.
<sup>c</sup> Tukey test: A/A vs. A/C = P < 0.05; A/A vs. A/C = ns; A/C vs. C/C = P < 0.05.
<sup>d</sup> Tukey test: A/A vs. C/C = P < 0.05; A/A vs. A/C = ns; A/C vs. C/C = ns.
<sup>e</sup> Tukey test: A/A vs. C/C = P < 0.05; A/A vs. A/C = P < 0.05; A/C vs. C/C = P < 0.05.
TABLE 3. Clinical and hormonal features of 112 patients with TS grouped according to combined GHR-exon 3 and −202 IGFBP3 genotypes

<table>
<thead>
<tr>
<th>GHR-exon 3 and −202 IGFBP3 genotypes</th>
<th>d3/* + A/* (1)</th>
<th>fl/fl + A/* or d3/* + C/C (2)</th>
<th>fl/fl + C/C (3)</th>
<th>P (1) vs. (2) vs. (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients for short-term outcomes</td>
<td>44</td>
<td>37</td>
<td>31</td>
<td>ns</td>
</tr>
<tr>
<td>Karyotype 45,X</td>
<td>50%</td>
<td>56%</td>
<td>49%</td>
<td></td>
</tr>
<tr>
<td>Target height SDS</td>
<td>−0.6 ± 0.8</td>
<td>−0.8 ± 0.8</td>
<td>−1 ± 0.9</td>
<td>ns</td>
</tr>
<tr>
<td>Chronological age at the start of therapy (yr)</td>
<td>11 ± 3.6</td>
<td>11 ± 3.7</td>
<td>12 ± 4</td>
<td>ns</td>
</tr>
<tr>
<td>BA at the start of therapy (yr)</td>
<td>9 ± 3.1</td>
<td>9 ± 3.1</td>
<td>10 ± 3.1</td>
<td>ns</td>
</tr>
<tr>
<td>Height SDS at the start of therapy</td>
<td>−3.0 ± 0.9</td>
<td>−3.1 ± 1.2</td>
<td>−3.7 ± 1.3</td>
<td>0.023b</td>
</tr>
<tr>
<td>BMI SDS at the start of therapy</td>
<td>0.7 ± 1.1</td>
<td>0.4 ± 1.0</td>
<td>0.8 ± 1.2</td>
<td>ns</td>
</tr>
<tr>
<td>Mean rhGH dose (µg/kg · d)</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>ns</td>
</tr>
<tr>
<td>First-year growth velocity (cm/yr)</td>
<td>7.8 ± 1.6</td>
<td>6.8 ± 1.9</td>
<td>6.0 ± 2.0</td>
<td>&lt;0.001c</td>
</tr>
<tr>
<td>IGF-I SDS before rhGH therapy</td>
<td>−0.1 ± 1.6</td>
<td>−0.3 ± 1.3</td>
<td>−0.8 ± 1.3</td>
<td>ns</td>
</tr>
<tr>
<td>IGFBP-3 3 SDS before rhGH therapy</td>
<td>1.9 ± 2.0</td>
<td>1.7 ± 1.6</td>
<td>1.1 ± 1.9</td>
<td>ns</td>
</tr>
<tr>
<td>IGF-I 3 SDS after first year of rhGH therapy</td>
<td>0.2 ± 1.6</td>
<td>0.2 ± 1.0</td>
<td>−1.1 ± 0.8</td>
<td>&lt;0.001d</td>
</tr>
<tr>
<td>IGFBP-3 3 SDS after first year of rhGH therapy</td>
<td>1.1 ± 0.9</td>
<td>0.6 ± 0.8</td>
<td>0.4 ± 1.1</td>
<td>0.004c</td>
</tr>
<tr>
<td>Number of patients for long-term outcomes</td>
<td>27</td>
<td>21</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Spontaneous induced puberty</td>
<td>6.21</td>
<td>3.18</td>
<td>1.16</td>
<td>ns</td>
</tr>
<tr>
<td>Chronological age at onset of puberty (yr)</td>
<td>14.0 ± 1.9</td>
<td>14.5 ± 2.3</td>
<td>15.0 ± 2.8</td>
<td>ns</td>
</tr>
<tr>
<td>rhGH therapy before onset of puberty (yr)</td>
<td>4.0 ± 2.6</td>
<td>3.0 ± 2.0</td>
<td>3.0 ± 2.0</td>
<td>ns</td>
</tr>
<tr>
<td>Duration of rhGH therapy (yr)</td>
<td>5.0 ± 2.5</td>
<td>4.5 ± 2.4</td>
<td>5.0 ± 2.4</td>
<td>ns</td>
</tr>
<tr>
<td>Adult height SDS</td>
<td>−1.3 ± 0.7</td>
<td>−2.2 ± 1.8</td>
<td>−2.7 ± 0.8</td>
<td>&lt;0.001c</td>
</tr>
<tr>
<td>Adult height-target height SDS</td>
<td>−0.7 ± 0.9</td>
<td>−1.4 ± 0.9</td>
<td>−1.6 ± 1.4</td>
<td>0.014b</td>
</tr>
<tr>
<td>Height gain SDS</td>
<td>1.3 ± 1.1</td>
<td>0.8 ± 1.3</td>
<td>0.6 ± 1.6</td>
<td>ns</td>
</tr>
</tbody>
</table>

ns, Not significant.

a One-way ANOVA.

b Tukey test: (1) vs. (3) = P < 0.05; (1) vs. (2) = ns; (2) vs. (3) = ns.

c Tukey test: (1) vs. (3) = P < 0.05; (1) vs. (2) = P < 0.05; (2) vs. (3) = ns.

d Tukey test: (1) vs. (3) = P < 0.05; (1) vs. (2) = ns; (2) vs. (3) = P < 0.05.

spite similar rhGH doses and duration of treatment, patients with TS who presented the combination of the two favorable genotypes (GHR-exon 3 d3/* + −202 A/* IGFBP3) reached adult height on average 1.4 SD (95% CI of 0.9−1.9, P < 0.001) higher than those girls with TS carrying unfavorable combined genotypes (GHR-exon 3 fl/fl ± −202 C/C IGFBP3; P < 0.001). Patients with intermediate genotypes (fl/fl + A/* or d3/* + C/C) had intermediate height between results (Table 3 and Fig. 1).

Alone, the GHR-exon 3 genotype accounted for 27% of adult height variation (P < 0.001), whereas the −202 A/C IGFBP3 genotype accounted for 24% (P < 0.001). Combined, these two variants were responsible for 37% of adult height variation (P < 0.001) and together with basal height SDS (P < 0.001) and chronological age at onset of puberty (P < 0.001) explained 61% of the observed variation.

**Discussion**

In recent years, rhGH pharmacogenetic studies demonstrated that common polymorphisms can modulate the response to rhGH treatment (11, 18–20). The addition of these genetic factors to established clinical variables might improve the accuracy of growth response prediction, allowing for individualized...
therapy. One of the limitations of rhGH pharmacogenetic studies is the significant variability in the etiology of short stature in some conditions in which rhGH therapy is used, such as idiopathic short stature and children born small for gestational age (SGA) (21, 22). TS, on the other hand, is a more homogeneous cause of short stature because SHOX gene haploinsufficiency is the main cause of growth impairment (23).

The present study confirmed the positive influence of GHR-d3 allele on not only the first year growth velocity (24) but also adult height outcomes (8) in patients with TS treated with rhGH. The absence of correlation between GHR-exon 3 genotype and growth response to rhGH in two previous studies in patients with TS can be partially explained by the small numbers of patients enrolled (9) and the paucity of individuals carrying the GHR-d3 allele (10), precluding sufficient statistical power. A published meta-analysis concluded that the GHR-d3 allele is associated with better growth response to rhGH in GHD and non-GHD children with short stature (7). Although alone the GHR-exon 3 genotype accounts for a slight difference in growth response between genotype groups (7), its association with other polymorphisms might improve prediction models resulting in a better individualization of rhGH treatment. In the present study, for the first time, the combined impact of genotypes at different loci on the magnitude of growth response to rhGH therapy in the patients with Turner syndrome was analyzed.

IGFBP-3 is known to modulate the actions of IGF and also exhibits distinct biological effects independent of the IGF/IGF-I receptor axis (25–29). The −202 A/C SNP of the IGFBP3 promoter region has been correlated with circulating IGFBP-3 levels in healthy adults (30), GHD children (11), and children born small for gestational age (12). In agreement with these findings, in the present study, patients with TS carrying the −202A-IGFBP3 allele also had mean IGFBP-3 levels higher than patients homozygous for the −202C-IGFBP3 allele. Additionally, the presence of the −202A-IGFBP3 allele was also associated with better short- and long-term growth outcomes, similar to what was observed for patients with severe GHD (11).

It is noteworthy that the combined analysis of the GHR-exon 3 and −202 A/C IGFBP3 disclosed a clear nonadditive epistatic influence of these two common polymorphisms on adult height of patients with TS treated with rhGH (GHR-exon 3 alone, R² = 0.27; −202 A/C IGFBP3, R² = 0.24; the combined genotypes, R² = 0.37, Fig. 1). Together with the clinical factors, these genotypes accounted for 61% of variability in adult height of patients with TS after rhGH therapy.

We conclude that homozygosity for the GHR-exon3 full-length allele and −202 C-IGFBP3 allele are associated with less favorable short- and long-term growth outcomes after rhGH treatment in patients with Turner syndrome. Furthermore, these polymorphisms exhibit a nonadditive interaction in rhGH outcomes. The combined influence of multiple as-yet undiscovered genetic factors with the already known ones might improve the accuracy of the prediction of growth response allowing the desired personalized medicine. The idea of personalized treatment proposes that the combination of clinical and genetic factors could influence the treatment strategy in each individual patient, including the choice of drug dose. Our data support the idea that rhGH dose should be tailored at the start of treatment according to the worst/best clinical and genotypic profile. This concept needs to be proved in prospective studies. Patients with less favorable genotypes could benefit from higher rhGH doses improving height outcome. On the other hand, patients with the best responsive genotypes could benefit from dose reduction and consequently treatment cost and side effects without impairment in height outcome.

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Disclosure Summary: The authors declare there is no conflict of interest that could be perceived as influencing the impartiality of the research reported.

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